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Study of near surface boundary layer characteristics during pre-monsoon seasons using micrometeorological tower observations

S. CHAUDHURI and A. MIDDEY
Department of Atmospheric Sciences, University of Calcutta, 51/2 Hazra Road, Kolkata-700 019, India
Corresponding author: S. Chaudhuri; e-mail: chaudhuri_sutapa@yahoo.com

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RESUMEN

El estudio de la capa límite es imperativo, ya que las condiciones meteorológicas adversas en esta parte de la atmósfera afectan el ambiente y diversos aspectos de las actividades de un país, y repercuten en el entorno socioeconómico de una región. Las características de la capa límite superficial se estudian por medio de la variación vertical de flujos de calor, humedad, ímpetu y energía cinética, así como del número de Richardson, durante la temporada previa al monzón (abril-mayo) en Kharagpur (22º 30' N, 87º 20' E) y Ranchi (23º 32' N, 85º 32' E), con datos provenientes de torres de 50 y 32 m de altura, respectivamente, en días con y sin tormenta. Se observa que la variación temporal de los flujos dentro de la capa límite y la energía cinética en varias alturas logarítmicas son significativas al comparar días con tormenta y sin ella. Los flujos de calor y de ímpetu exhiben picos máximos mientras que el flujo de humedad muestra una disminución súbita justo antes de la tormenta. Las condiciones del viento desempeñan un papel crucial en la estación de Kharagpur, situada tierra adentro en las cercanías del Golfo de Bengala, a diferencia de la estación de Ranchi, ubicada en un terreno montañoso de Chotanagpur. El estudio micrometeorológico de la capa límite supuso un importante hallazgo concerniente a la observación de las tormentas, pues se observó que la razón de la temperatura potencial (θ) y la temperatura potencial equivalente (θe) se mantiene dentro de los límites de un rango crítico de 0.85 a 0.90 durante el tránsito de estos fenómenos.

ABSTRACT

Studying the boundary layer is imperative because severe weather in this portion of the atmosphere impacts on environment and various facets of national activities and affects the socioeconomic scenario of a region. Near surface boundary layer characteristics are investigated through the vertical variation of fluxes of heat, moisture, momentum, kinetic energy and Richardson number during the pre-monsoon season (April-May) at Kharagpur (22º 30' N, 87º 20' E) and Ranchi (23º 32' N, 85º 32' E) with 50 and 32 m tower data, respectively, on thunderstorm and non-thunderstorm days. The temporal variation of fluxes within the boundary layer and the kinetic energy at different logarithmic heights are observed to vary significantly between thunderstorm and non-thunderstorm days. The heat and momentum fluxes show a maximum peak while the moisture flux shows a sudden attenuation just before the occurrence of thunderstorms. The wind field depicts to play a crucial role at the inland station Kharagpur, which is in the proximity of the Bay of Bengal, compared to the station Ranchi, situated over hilly terrain on Chotanagpur. The micrometeorological study of the boundary layer reveals a significant finding pertaining to observe the passage of thunderstorms. It is observed that the ratio of the potential temperature (θ) and equivalent potential temperature (θe) remains confined within a critical range between 0.85 and 0.90 during the passage of thunderstorms.

Keywords: Boundary layer, boundary layer characteristics, tower observation, moist thermodynamic parameter, thunderstorm, thunderstorm forecast, thunderstorm genesis.

1. Introduction

The earth's surface is the only boundary in the domain of the atmosphere. The characteristics of the atmosphere near the surface are highly influenced by surface friction, convection, turbulence and its interaction with the free atmosphere. The surface layer is the region at the bottom of the boundary layer where turbulent fluxes vary less than 10% of their magnitude (Stull, 1988). The growth of the convective boundary layer (CBL) is driven by both surface fluxes of heat and moisture and the entrainment of warm and dry air from the free atmosphere (Kang, 2009). The transfer of energy from the generated mesoscale motions to the CBL turbulence results in the absence of a spectral gap between the two scales (Nieuwstadt and Brost, 1986). One of the most important features of the atmospheric boundary layer (ABL) is the ability to diffuse momentum, heat and moisture across it (Grant, 1986). Boundary layer height, the vertical profiles of the mass flux and the updraft area fraction can be determined from large eddy simulations (LES) (Blackadar, 1962; Brown, 1996). The boundary layer transports water vapor and heat to the free atmosphere, and the kinetic energy of the atmosphere is lost by dissipation (Sutton, 1953). The characteristics of turbulence in the thermally stratified atmospheric surface layer can be expressed in terms of the surface layer similarity theory (Kaimal *et al.*, 1976; Sorbjan, 2008). The turbulent fluxes (Panofsky and Dutton, 1984) of momentum, heat and moisture can be expressed using an analogy to molecular diffusion as:

$$\tau = K_m \rho \frac{\partial \overline{u}}{\partial z} \tag{1}$$

$$H = -K_h \rho C_P \frac{\partial \overline{\theta}}{\partial z} \tag{2}$$

$$E = -K_q \rho C_P \frac{\partial \overline{q}}{\partial z} \tag{3}$$

where τ, H and E are the flux of momentum, heat and moisture, respectively; K_m, K_h, K_q are the exchange coefficients of momentum, heat and moisture fluxes, respectively; and $\overline{u}, \overline{\theta}, \overline{q}$ are the means of wind velocity, potential temperature and specific humidity, respectively. C_P is the specific heat of air at constant pressure and ρ is the density of air. The fluxes are approximately constant with height in the surface layer (Businger *et al.*, 1971; Deardorff, 1974). The interaction between the low level shear and the gust front is vital for the maintenance of erect updrafts in long-lived convective systems (Rotunno *et al.*, 1988). The friction velocity u_* represents the velocity scale. The vertical change in the mean wind can be represented by u_* as

$$\frac{\partial \overline{u}}{\partial z} = \frac{u_*}{kz} \tag{4}$$

where k is the von Karman constant.